9286 STARS: AN AGGLOMERATION OF STELLAR POLARIZATION CATALOGS

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ABSTRACT

We present an agglomeration of stellar polarization catalogs with results for 9286 stars. We have endeavored to eliminate errors, provide accurate (∼arcsecond) positions, sensibly weight multiple observations of the same star, and provide reasonable distances.

This catalog is available by anonymous FTP as ascii file */pub/polcat/p14.out* at *vermi.berkeley.edu*. This manuscript is also available at the same site as file *pol1.ps*.

Subject headings: catalogs — ISM: magnetic fields — ISM: dust, extinction — stars: distances

1. INTRODUCTION

Polarization has been measured for thousands of stars and presented in perhaps a dozen catalogs. Some previous attempts to combine these lists are very admirable because they have made it much easier to use the data. The largest include Mathewson et al (1978; hereafter MFKNK) catalog (CDS catalog II/34A) and Axon and Ellis (1976) (CDS catalog II/178). However, they have deficiencies; for example, both list multiple results for individual stars and have not purged errors from the original catalogs. The present agglomeration combines multiple observations with weighted averages, fixes most errors, provides accurate positions, and reasonable estimates for stellar parameters such as distance and extinction. It also includes information on which original catalogs were used for each entry.

Section 3 discusses the catalogs that we have included, together with the information contained in each. The MFKNK, Axon and Ellis (1976), Reiz and Franco (1998) and Goodman (1997) catalogs were originally provided to us in electronic form. We entered the Appenzeller (1974) catalog by hand from the printed page. For all the other catalogs, we scanned printed versions and converted them to ascii files. However, in the final analysis, all of these catalogs contain data that were entered into a computer file by hand. Therefore they contain potential errors. Heiles (1997) recounts a few problems regarding such errors, and one goal was to eliminate as many problems as possible.

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2. FINDING AND FIXING POSITION AND IDENTIFICATION ERRORS

Nearly all positions in our agglomeration are derived from one of the four primary stellar databases, which are the Hipparcos, Tycho, SAO, and SIMBAD databases. Below we refer to these as the *primary stellar databases*. In our agglomeration, $IDCAT$ tells which of these databases provided the position.

Many catalogs provide both positions and an identification number (an HD, BD, CD, or CPD number). However, sometimes the position and identification number are incommensurate. We caught these problems by comparing the polarization catalog's star identity and position with those from the primary stellar databases. Comparison with Hipparcos, Tycho, and SAO was done automatically when one or more actually listed the catalog star, which was the case for about 98% of the stars. For the remaining stars we examined the SIMBAD database by hand. The polarization catalogs usually list positions to within a few arcminutes; our criterion for acceptance of the catalog star as listed was that the catalog and primary stellar database positions agree to within $5.4'$. This tolerance may seem overly large, but we are confident that it is reasonable on the basis of empirical examination.

In every case of a successful identification, we adopted the position from the primary stellar database instead of from the polarization catalog. This means that our positions are accurate at the arcsecond level. For the automatic comparisons there is no ambiguity or possibility for error. For our SIMBAD identifications there is a possibility for error in our compilation because we entered the identification and positional information by hand. However, if we did make a mistake in this process, then the position can be incorrect by up to $\sim 10'$ but no larger, because larger position discrepancies would have been caught automatically. For some cases of SIMBAD identifications, the star identification name was not entered in the appropriate field; however, the star position is correct.

There were a nontrivial number of unsuccessful identifications, and because polarization data are valuable but few, so we attempted to discover why. For unsuccessful comparisons there are three possibilities: the original polarization catalog contains a simple, single typographical error; it contains multiple typographical errors; the identification or position is simply incorrect.

We first attempted to reconcile all discrepancies to a simple, single typographical error. We assumed that if there was an error in any *one* of the right ascension, declination, or star identification, then we could reasonably assume that the error was typographical. This was the case for the overwhelming majority of discrepant objects, and we made the appropriate change in the original database; we do not flag such typographical errors in our compilation. If there was an error in *more than one* of the three parameters, then we assumed that the error was fundamental and flagged it by setting $IDCAT = -999$[2]. Some stars have no listing in any of the four stellar

[2]The one exception to this rule was several stars in the MFKNK catalog that had large errors in declination—one was listed with 75° instead of 57° and a few with the wrong sign. Because of the precession, mentioned below, not

position databases and they also have $IDCAT = -999$.

In summary, the positions or identification numbers of stars that have $IDCAT = -999$ are not absolutely certain, either because the information is discrepant or because there wasn't enough information available to check. Finally, an entry in any parameters of -999, -999.9, or -99 means that the information was not available.

3. COMMENTS ON INDIVIDUAL POLARIZATION CATALOGS

The following comments are not guaranteed to be complete or accurate. The listing is in the reverse order of $POLREFS$ in Table 3.

3.1. The MFKNK catalog

The MFKNK catalog is available from the CDS catalog service as catalog number II/74A. It is a huge compilation of, first, the original Mathewson and Ford (1970; MF) compilation of their own and others measurements; and the Klare and Neckel (1978; KN) measurements. The KN data set is a particularly valuable addition because it contains many stars in the third and fourth Galactic quadrants. However, the error rate in the KN section of the MFKNK catalog is relatively large. This is strange because the *paper* version of the KN catalog differs from the MFKNK *electronic* version, and in cases of discrepancy it is the *paper* version that is correct. A few examples: –58 510 is really HD 58510; HD 290377 is really HD 298377; –63 1513 is really –63 2513.

MFKNK had a systematic error: all declinations in the range $0^\circ \rightarrow -1^\circ$ were denoted as positive instead of negative. MFKNK list positions for equinox 1950, but most of their star positions are derived from lists where the equinox was 1900. Thus MFKNK precessed the 1900 positions forward by 50 years to get their 1950 positions, and it seems that the negative signs were missing in the original 1900 positions too. This means that their 1950 declinations contain more than just a simple sign error. Positions in our agglomeration are correct, having been taken from the stellar databases.

All of the equatorial position angles in MFKNK for their reference 6 (Schmidt) were set equal to zero, probably because the original reference listed all results in Galactic coordinates. We assumed that the Galactic angles listed were correct.

Many polarizations listed in MFKNK are zero; these measurements are really upper limits, and we did not include these incorrect results in our final list or in our weighted averages.

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only the declinations but also the 1950 right ascensions are incorrect; we did not flag these stars with –999.

3.2. BERDYUGIN, SNARE, AND TEERIKORPI

Berdyugin et al (1995) observed 51 stars at high positive Galactic latitudes and provided identifications, positions, and polarization, position angle (both equatorial and Galactic), visual magnitude, E(b–y), and distance. Five stars had unmeasurably low polarization and we omitted them. For one star, BD +20 2870, the equatorial and Galactic position angles do not agree; we assume this is a typographical error but have no way of knowing which angle is the correct one. We include this star, but the large $\theta_{diff} \sim 70^\circ$ is telling. In our compilation, which lists E(B–V) when it is available, we have converted E(b–y) by multiplying by the factor 11/8, which is the ratio of the separation of central wavelengths of (B–V) and (b–y).

3.3. KORHONEN AND REIZ

Korhonen and Reiz (1986) observed about 470 stars and provide identifications, positions, and polarization, position angle (both equatorial and Galactic), and visual magnitude. There are two groups of stars: their Table 1 contains 118 stars that were previously observed by MF, and they provide detailed comparisons of the results; their Tables 2 and 3 contain 357 additional stars. Table 1 had one identification error and, in addition, the conversions to Galactic coordinates and to Galactic position angle for HD 1461 were incorrect; we accept the equatorial position angle. Table 3 had two minor positional errors; also, SAO 167576 had a small error in conversion to Galactic coordinates and to Galactic position angle, which we ignore.

3.4. KRAUTTER

Krautter (1980) observed 313 stars, mostly near the Galactic plane, and provided identifications, positions, polarization, position angle (both equatorial and Galactic), visual magnitude, spectral type, B–V, A_V, and distance. There are a few positional errors.

3.5. MARKKANEN

Markkannen (1979) observed 31 stars and presented an additional 41 from Appenzeller (1968; these also exist in MFKNK); he was studying the North Galactic Polar region. He provided identifications, polarization, position angle, visual magnitude, spectral type, and distance. He did not provide positions, so we cannot be absolutely certain about typographical errors. Many stars had unmeasurably low polarization and we omitted them. There are two identification errors: HD 110056 is really HD 111056; and we eliminated HD 114727, which must be misidentified because it lies too far outside his area of interest.

3.6. SCHROEDER

Schroeder (1976) observed 495 stars and provided identifications, positions, and polarization, position angle (both equatorial and Galactic), visual magnitude, spectral type, and distance. For identification he provided either HD numbers or numbers from the General Catalogue of Trigonometric Parallaxes (Jenkins 1963); for the latter, we obtained the BD, CD, or CPD numbers. There seems to be one identification error: GCT 301 is the same as either CD –52 291 or CPD –52 291, but the Schroder positions do not agree with SIMBAD's.

3.7. APPENZELLER

Appenzeller (1974) studied 126 stars in the vicinity of Eridanus loop region and concluded that the magnetic field was deformed in the shape of a "magnetic pocket". He provided identifications, positions, and polarization, position angle, but no spectral types or colors. The star he lists as HD 288553 is really HD 288353.

3.8. GOODMAN

Goodman's (1997) catalog contains stars primarily in or near dark clouds and contains only positions and measured polarizations. There are no stellar identification data, so we could not perform checks on position and we set $IDCAT = -999$ for all of Goodman's stars.

3.9. LEROY

Leroy observed about 1000 nearby stars and found zero polarization in most of them. However, 25 of these stars have measurable polarization (Leroy 1993). Leroy provided stellar identifications, positions, polarization, position angles in both equatorial and galactic coordinates, spectral type, and distance. We detected no typos in Leroy's list. Leroy gave two distances; we used his distances D_i, which are supposed to be better.

3.10. BEL, LAFON, AND LEROY

Bel et al (1993) observed stars near the Cepheus flare (near the NCP) and provided identifications, positions, distance, polarization, and position angle in Galactic coordinates. There were 133 entries and two typographical errors on positions, for S10278 and HD 678. The distances for many stars have alphameric suffixes such as "mx", and these are unexplained; we have ignored them.

3.11. REIZ AND FRANCO

Reiz and Franco (1998) measured 361 stars that sample 35 of Kapteyn's selected areas in the third and fourth Galactic quadrants for $|b| \leq 30°$. This catalog appears to have accurate photometry, reddening, and distances. Before this paper appeared, we had finished a preliminary version of the agglomeration in which we had specified E(B–V) to only one decimal place. This accuracy is insufficient for Reiz and Franco's catalog, so we list their entries to two decimal places. As with Berdyugin et al (1995), we converted E(b–y) to E(B–V) by multiplying by the factor 11/8. This catalog provides measurements at three wavelengths for every star. We averaged these according to the prescription below in section 4.

The Reiz/Franco catalog contained four stars that already existed in our preliminary agglomeration: HD98310, HD98722, HD99545, and HD100198. For these stars we followed the easier option of choosing the better data instead of taking a weighted average. In two cases, HD98310 and HD100198, the older polarization errors from MFKNK were smaller so we used the MFKNK data.

It is instructive to compare the distances: For the first two stars the Reiz/Franco distances were comparable with the Neckel et al (1980) ones. However, for the last two the distances were widely discrepant. HD99545 had distances (412, 3020) pc for (Reiz/Franco, MFKNK) and HD100198 had distances (188, 2371) pc for (Reiz/Franco, Neckel et al). It is difficult to know which distances are correct. HD99545 is a particularly difficult case because the Reiz/Franco (polarization, reddening, distance) are about $(\frac{1}{2}, \frac{1}{3}, \frac{1}{8})$ the MFKNK values; this makes the set of parameters reasonably compatible for *both* Reiz/Franco and MFKNK. We chose the Reiz/Franco polarization, reddening, and distance. The case of HD100198 is much clearer: the polarization and reddening are both large and incompatible with the 188 pc Reiz/Franco distance, so we chose the Neckel et al distance.

These two huge disrepancies, and particularly the one for HD100198, are illustrative of the generic problems with photometric distances. *Caveat emptor!*

4. COMBINING THE POLARIZATIONS

Whenever a star was listed more than once we took a weighted average of the Stokes parameters in the different catalogs. The weights were equal to the reciprocals of the squares of the uncertainties in polarization percentage. Most catalogs list the formal uncertainty for individual stars. However, neither MFKNK nor Goodman list uncertainties for individual stars. In MFKNK there are different original sources and we assigned uncertainties in percent polarization Δp as in Table 1; for Goodman, we adopted $\Delta p = 0.1\%$.

We list the percent polarization and position angle, and their uncertainties, as derived from the weighted average of the Stokes parameters. The definition of these uncertainties is slightly arbitrary for the following reason. In principle, the errors in Stokes Q and U propagate into the errors in the final polarization percentage and position angle; Schroder provides the relevant equations. However, if one follows the procedure that we did—namely, to calculate Q and U from the polarization percentage and angle, average the Stokes parameters, and obtain the new average polarization percentage and angle—then the errors in the final average depend on the position angle of the original results. That is, the calculated uncertainty in the final result will generally be different if one uses different zero points for the definition of position angle, for example using Galactic versus Equatorial position angles. This is clearly unacceptable.

We solved this problem by using a modified version of the proper formulae, as follows:

$$pp = \sqrt{\langle Q\rangle^2 + \langle U\rangle^2} \tag{1a}$$

$$\theta = 0.5 \text{ atan}\left(\frac{\langle \text{U}\rangle}{\langle \text{Q}\rangle}\right) \tag{1b}$$

$$\sigma(pp) = \sqrt{(\sigma(\langle Q\rangle)^2 + \sigma(\langle U\rangle)^2} \tag{1c}$$

$$\sigma(\theta) = \text{atan}\left(\frac{0.5\sigma(pp)}{pp}\right) \tag{1d}$$

In these equations, $\langle Q\rangle$ is the weighted average of Q as defined above. Also, $\sigma(\langle Q\rangle)^2$ is the weighted average of the squares of the residuals $(Q_i - \langle Q\rangle)^2$, where the subscript i represents the different measurements and again the weighted average is defined above.

The polarization uncertainties given in the catalogs are not always consistent with results when comparing one catalog with another. Schroeder (1976) provides an illustrative graphical summary of the comparisons between his results and others. There are significant random differences and also systematic differences in polarization percentage. Angles are better defined except for some cases where there are extremely large differences.

Generally speaking, one should be cautious: unless polarizations are large, systematic errors and perhaps underquoted random errors may make results appear more reliable than they really are.

5. DISTANCES

We compared the distances in various catalogs; most distances were consistent to within, say, 20%. However, there were some that were highly discrepant. We present an illustrative example.

All catalogs except for Leroy's used spectroscopic parallax. We selected a set of the worst-agreeing distances and investigated them in SIMBAD. For example, for HD 63964 Axon and Ellis (1976) list 45 pc, MFKNK list 40 pc, while Krautter lists 1640 pc. SIMBAD says this is an

F5Ib star, with VMAG 8.2; without extinction, its distance modulus is 12.8 mag, so its distance is 3600 pc if there is no extinction. Clearly, Krautter's larger distance is correct.

Rather than take averages of distances, we generated a priority list (Table 2) based in part on the amount of information given in the original polarization catalogs; the more information (such as extinction), the higher the priority. We updated the spectral type, distance, and reddening where possible; where not, we did whatever we could. Apart from Reiz and Franco (1998), we assigned the highest priority to Neckel, Klare, and Sarcander (1980; CDS catalog II/62); this catalog is devoted exclusively to distances and extinctions and they seem to have taken great care.

All distances are photometric and correspondingly uncertain because they depend on accurate spectral classification. Errors in distance are sometimes larger than a factor of ten. See the discussion above of the Reiz and Franco (1998) catalog!

6. DESCRIPTION OF AGGLOMERATION FILE

Table 3 provides a byte-by-byte description of the agglomeration file. It contains 9286 entries, sorted in order of declination and right ascension as embodied in $DECRA$.

We provide the following specific cautions:

(1) If HDNR, BDNR, CDNR, and CPDNR all equal –999 or zero, then we are relying on the stellar position as given in the original catalog. There is a possibility that either the stellar identification or the position is incorrect.

(2) If the position came from SIMBAD, denoted by $IDCAT = 4$ or 5, then there is a small possibility of the position being incorrect because of typographical error. $IDCAT = 4$ means that SIMBAD provided positions to arcsecond accuracy or better; $IDCAT = 5$ means that SIMBAD's accuracy was less, more like an arcminute.

(3) If $IDCAT$ equals –999 or zero, then the stellar position and/or the identification may be incorrect; see section 2. $IDCAT = -998$ means that we happened to notice a more serious problem such as a close pair of stars; we noticed only two such entries, HD138917 and HD232588, but there might be many more.

(4) The entry θ_{diff} should be small. Large values indicate a typographical error in the original polarization catalog, and we do not know whether the equatorial or Galactic position angle was given correctly. Five stars have $\theta_{diff} > 10°$ and should perhaps be excluded.

(5) Values of –999.9 or –99.9 mean that the parameter was not given in the original catalog.

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Table 1. ADOPTED UNCERTAINTIES IN PERCENTAGE POLARIZATION FOR MFKNK

MFKNK REF NR	REFERENCE AUTHOR	Δp
0	Unidentified	0.1
1	Appenzeller (1966)	0.032
2	Appenzeller (1968)	0.032
3	Behr (1959)	0.12
4	Hall (1958)	0.20
5	van Smith (1956)	0.40
6	Schmidt (1968)	0.10
7	Hiltner (1956)	0.18
8	Klare and Neckel (1977)	0.10
9	Mathewson and Ford (1970)	larger of (3.5% or 1.1% $\times 10^{0.2VMAG}$)

Table 2. PRIORITY OF DISTANCES

NAME OF CATALOG	DISTCAT
Neckel et al (1980)	120
Reiz and Franco (1998)	130
Klare/Neckel in MFKNK	9
MF in MFKNK	10
Krautter (1980)	40
Schmidt in MFKNK	7
Appenzeller in MFKNK	2, 3
Behr in MFKNK	4
Hall in MFKNK	5
Hiltner in MFKNK	8
van Smith in MFKNK	6
MFKNK/other	1
Schroeder (1976)	60
Markkanen (1979)	50
Leroy (1993)	90
Berdyugin et al (1995)	20
Bel et al (1993)	100
Korhonen and Reiz (1986)	30
Axon and Ellis (1976)	110

Table 3. BYTE-BY-BYTE DESCRIPTION OF AGGLOMERATION FILE

BYTES	FORMAT	LABEL	EXPLANATION
1-18	F18.8	$DECRA$	$(\delta.alpha)^a_{2000}$
29-38	F10.1	HDNR	HD number
39-49	F11.6	BDNR	Bonner DM number
50-60	F11.6	CDNR	Cordoba DM number
61-71	F11.6	CPDNR	Cape DM number
72-80	F9.3	pp	percentage polarization
81-89	F9.3	Δpp	1σ uncertainty in pp
90-96	F7.1	θ_{eq}	position angle, equatorial, deg
97-103	F7.1	$\Delta\theta$	1σ uncertainty in position angle
104-110	F7.1	θ_{Gal}	position angle, Galactic
111-119	F9.4	ℓ	Galactic longitude, degrees
120-129	F9.4	b	Galactic latitude
130-136	F7.2	E(B–V)	reddening, mag
137-143	F7.1	θ_{diff}	discrepancy between θ_{eq} and θ^b_{gal}
144-148	I5	$IDCAT$	Primary stellar database[c]
149-155	F7.1	VMAG	visual magnitude
156-163	f8.1	DISTANCE	distance, pc
164-179	A16	SP	spectral type
180-191	22I1	POLREFS	polarization catalog numbers[d]
192-296	I5	DISTCAT	distance catalog[e]

[a]The declination, in units of 10^{-4} decimal degrees, is to the left of the decimal point; the right ascension, in units of 10^{-4} decimal hours, is to the right of the decimal point. For example, -123456.05432100 is $\delta = -12.3456^\circ$, $\alpha = 05.4321^h$.

[b]θ_{diff} is the discrepancy between the position angles in Galactic and Equatorial coordinates in the original catalog. Nonzero entries represent errors in coordinate conversion in the original catalog, and the angle may be wrong in one or both coordinate systems.

[c]$IDCAT = [1,2,3,4,5]$ means [Hipparcos, Tycho, SAO, SIMBAD(arcsec accuracy), SIMBAD($\sim$ arcmin accuracy)], respectively. Also, see section 6. $IDCAT = -999$ or 0 means that that the stellar position and/or the identification may be incorrect. $IDCAT = -998$ means that we happened to notice a more serious problem such as a close pair of stars; we noticed only two such entries, HD138917 and HD232588, but there might be many more.

[d]POLREFS is 22 binary numbers, with 1 meaning a particular catalog was used and 0 meaning it was not. Let us define n_b as the particular binary number, where $n_b = 0 \rightarrow 21$; each binary number occupies byte $185 + n_b$. Each n_b corresponds to a particular reference, as follows: 0, no entries; 1, no entries; 2, Reiz and Franco (1998); 3, Bel et al (1993); 4, Leroy (1993); 5, Goodman (1997); 6, Appenzeller (1974); 7, Schroeder (1976); 8, Markkannen (1979); 9, Krautter (1980); 10, Korhonen and Reiz (1986); 11, Berdyugin et al (1995); 12-21, the 10 different references within MFKNK. For ($n_b = 12 \rightarrow 21$), we have ($n_b = 22 - DISTCAT$), where ($1 \leq DISTCAT \leq 10$) and is listed in Table 2. For example, Behr in MFKNK has DISTCAT = 4, so it is represented by a 1 in position 18.

[e]From Table 2.